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5 **Emergency Department Crowding in Relation to In-Hospital Adverse Medical Events:**
6 **A Large Prospective Observational Cohort Study**

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ABSTRACT

Background: Emergency department (ED) crowding has been linked with adverse medical events. However, this association was inadequately controlled for potential confounding variables.

Objectives: To investigate whether ED crowding is independently associated with risk of in-hospital death and morbidity, and longer total hospital stay.

Methods: Prospective observational cohort study of all patients (≥ 18 years) presenting to the ED of an academic teaching hospital in [xxx] from June 21, 2010, to July 20, 2012. Multivariate logistic regression and proportional hazard analysis was used to control for risk factors. ED occupancy was determined for 108229 included patients and labeled “ED crowding” when occupancy was within the highest quartile of occupancy. Outcomes within 10 days of ED admission included in-hospital death, hospital-acquired morbidities and total hospital stay.

Results: During ED crowding, a median of 58 (IQR 55-63) patients were present for 40 licensed treatment bays. After controlling for all baseline risk factors and as compared with the lowest quartile of ED occupancy (30 [26-32] patients), ED crowding was not independently associated with mortality (OR 0.94, 95% CI [0.74-1.19]; $p=0.6$), but tended to be associated with higher incidence of hospital-acquired pneumonia (OR 1.24 [0.96-1.62]; $p=0.09$).

Conclusions: Failing to control for baseline risk factors may have led to false-positive associations between ED crowding and mortality in previous studies. After controlling for risk factors we showed that ED crowding was associated with longer hospital stays but not with increased mortality.

44 **Keywords:** emergency department; crowding; adverse events; length of stay

INTRODUCTION

Since the 1999 report, “To Err is Human” produced by the Institute of Medicine (IOM), the general public was made aware that adverse events in medicine are one of the leading causes of morbidity and mortality in the United States (1). An adverse event is defined as an unintended injury caused by medical management rather than by a disease process and is an event that results in death, life threatening illness, disability at time of discharge, admission to hospital, or prolongation of hospital stay [2]. Examination of medical records is generally considered to be the gold standard for accurately monitoring adverse events [3].

In spite of a growing patient-safety movement worldwide, health care has not become measurably safer [4, 5]. Health care is one of the few risk-prone social domains in which pressures of public demand irrationally limits the use of common sense and safety-enhancing solutions; for example, limiting the flow of and prioritizing incoming patients [6]. The latter is especially true for emergency departments (EDs), since they deliver an important public service by providing emergency care 24 hours a day, 365 days a year, without discriminating against any particular social or economic status.

ED crowding is recognized as being a major, international problem that affects patients and providers [7]. A recent report from the IOM noted that the increasing strain caused by crowding is creating a deficit in quality emergency care [8]. Indeed, crowding is reported to be linked with impaired or denied access to emergency medical services [9-13], higher patient mortality [14, 15], and higher patient-care costs [16, 17]. Nevertheless, several unresolved, or unaddressed, issues remain with regard to the association between ED crowding and adverse events. First, existing evidence on adverse events is largely anecdotal and inconclusive [18]. Second, many studies have failed to adequately disentangle the observed ED crowding-adverse events association from potential confounding variables that

could be masking the true picture. One such confounding variable that has not been controlled for is severity of illness upon ED admission. [14, 15, 19, 20]. Finally, explanations for the observed associations between ED crowding and adverse outcomes remain merely speculative [16, 21, 22].

We performed a large prospective observational study adequately powered to investigate whether ED crowding is independently associated with a higher incidence of adverse events, such as death and several morbidity outcomes, and whether it is associated with a longer duration of hospital stay. The specific hypothesis is whether the highest quartile of ED occupancy is associated with the studied adverse outcomes, once baseline risk factors are controlled for statistically.

MATERIALS and METHODS

Design Overview

We performed a large prospective observational cohort study in a tertiary referral academic teaching hospital in Leuven, Belgium. The primary study objective was to determine whether ED crowding was independently associated with in-hospital death occurring within 10 days of ED admission. The secondary objective was to analyze whether ED crowding was independently associated with five morbidity events occurring in hospitalized adult patients during the first 10 days after ED admission or with the total duration of hospital stay.

Setting and Participants

We determined the number of participants we needed in order to achieve a statistical power of 90% and a certainty of 95%. Assuming an overall mortality rate of 1%, a cohort of

104000 patients was required to identify an independent, 20% increase in relative risk of death (hazard ratio [HR] of 1.2) during ED crowding. For adult patients admitted to hospital wards after ED admission, a mortality rate of 3% was assumed. Therefore, a cohort of 30000 hospitalized patients was required to identify (same power) an independent 20% increase in relative risk of death during ED crowding in this subgroup.

Study Population

The academic teaching hospital in [xxx] has 1949 beds, with a mixed adult and pediatric population. The ED has an annual census of approximately 55000 patients, with an average hospital admission rate of 36%. Thirteen percent of hospital admissions are patients younger than 18 years of age. The ED consists of 40 licensed treatment bays, consisting of an admission and treatment area with 15 cubicles, and a 25-bed observation ward. Of these, 7 beds are equipped for intensive care and serve as a buffer zone for the intensive care unit (ICU) in times of ICU bed shortage. The ED is staffed by physicians and rotating residents from the departments of emergency medicine, internal medicine, pediatrics, trauma care, and psychiatry. Other specialties provide consultancy to the ED whenever required.

Treatment urgency and priority for patients presenting to the ED is determined according to the Emergency Severity Index (ESI), a five-level triage acuity tool; higher numbers indicate lower acuity [23].

All adult patients (≥ 18 years) presenting to the ED during a 2-year period, from June 21, 2010, to July 20, 2012, were eligible for inclusion in the study.

Data Collection

The ED occupancy rate was defined as the ratio of the total number of ED patients to the total number of licensed treatment bays per hour [24]. Since the number of licensed

treatment bays remained constant throughout the study, we used the raw number of ED patients to define crowding. The hospital administration computer system updated the total number of patients present at the ED every 10 minutes. For each of the included patients in the total cohort, the occupancy rate at the time of ED admission for that patient was calculated as the mean number of patients present at the ED in the epoch starting from 4 hours before ED admission of that patient up to a maximum of 4 hours after ED admission. The distribution of all individual mean ED occupancy rates was determined (Figure 1) and divided into four quartiles. The quartile with the highest occupancy (Q4) during the cohort period was considered as “ED crowding.” The least crowded quartile (Q1) was considered to be a reference value for the other quartiles (i.e., Q2 to Q4).

For all patients admitted to the ED during the 2-year study period, the following demographic characteristics and risk factors were prospectively collected from the hospital information system: age; gender; transport method (medically assisted transport versus other); time of arrival (season [winter versus other seasons], day of the week [weekend versus during the week], and time of day); triage category (1 to 5); and average hospital occupancy in percentage per 24 hours. Both transport methods (medically assisted transport or other) and triage acuity (ESI score 1 to 5) were considered to be proxy measures of illness severity. Prospectively collected outcome measures included information on ED and total hospital length of stay and in-hospital mortality within 10 days of ED admission. These outcomes were extracted from the hospital information system.

For adult patients admitted to hospital wards after ED admission, the principle investigator (SV) reviewed and analyzed medical records for the presence of five adverse morbidity events occurring up to 10 days after ED admission. The principle investigator was blinded with regard to ED crowding status. From here on, we refer to these patients as “follow-up patients.”

The five adverse events we assessed were 5 of 6 events comprising an established patient safety indicator (PSI), the “failure to rescue” PSI, which was developed by the Agency for Healthcare Research and Quality (AHRQ) [25]. We selected this PSI because of its clear clinical definition, which was based on highly prevalent events, and because, according to the literature, this PSI is related to unexpected death during hospital admission [26, 27].

The occurrence of a cardiac arrest event in the “failure to rescue” PSI could not be accurately identified for all patients in this study due to a lack of information in the files, and was therefore omitted. The remaining five adverse events were scored for this study: (a) hospital-acquired pneumonia, (b) pulmonary embolism/deep vein thrombosis (PE/DVT), (c) sepsis, (d) acute renal failure, and (e) gastrointestinal hemorrhage/gastric ulcer. The occurrence of these events was scored by searching the patient files using explicit clinical criteria (see Addendum).

Data required to score the aforementioned adverse events were extracted from the electronic medical records of all patients through a computerized search tool and downloaded into a carefully standardized FileMaker® admission form (Filemaker Pro 11®; FileMaker, Inc., Middlesex, United Kingdom).

Outcomes and Follow-up

The primary outcome measure was the risk-adjusted HR for in-hospital death occurring within 10 days of ED admission in crowding quartile Q4 versus occupancy quartiles Q1, Q2, and Q3. Secondary outcomes were (a) risk-adjusted odds ratios (ORs) for the five morbidity outcome measures and the association of such morbidity with hospital mortality within 10 days, and (b) total duration of hospital stay in crowding quartile Q4 versus occupancy quartiles Q1, Q2, and Q3.

Statistical Analysis

Data are described as numbers and percentages for nominal and categorical variables and as medians and interquartile ranges (IQRs) for continuous variables.

Univariate analyses were performed with the Chi-square test (Pearson) for nominal and categorical variables; the Wilcoxon signed-rank test was used for continuous variables. For time to event analyses, a Kaplan-Meier analysis with a proportional hazard calculation was performed, provided that the proportional hazard assumption was not violated [28]. Proportional hazard analysis was performed in a univariate model as well as in a multivariate model controlling for baseline characteristics and for severity of illness risk factors. HRs and 95% confidence intervals (CIs) are reported. For those times-to-event outcomes in which the proportional hazard assumption was violated, the outcome variable was dichotomized according to literature reference values and subsequently analyzed by nominal logistic regression analysis. For dichotomous nominal outcomes, a nominal logistic regression analysis was performed in a univariate model as well as in a multivariate model, controlling for baseline characteristics and severity of illness risk factors. ORs and 95% CIs are reported. P-values were considered significant when ≤ 0.05 . No corrections for multiple comparisons were performed.

Statistical analysis was performed with JMP 10[®], version 10.0.02 (SAS Institute, Inc.).

Ethical Approval and Study Registration

This prospective cohort study was registered with ClinicalTrials.gov as study number NCT01116323, and the protocol approved by the Institutional Ethical Review Board (B32220108508). Given the observational design of the study, in which only routine clinical data were used, the need for informed consent was waived.

Role of the Funding Source

The funding source had no role in the design, performance, or reporting of the study, or in the decision to submit the manuscript for publication.

RESULTS

During the 2-year study period, a total of 108229 adult patients visited the ED for treatment, of which 32866 were patients who were subsequently admitted to a hospital ward (30.4%). Baseline characteristics and severity of illness risk factors per quartile occupancy are shown in Tables 1, 2, and 3, for the total cohort of patients, the ED patients not subsequently admitted to hospital, and the follow-up patients, respectively.

For Q1, the median (IQR) for 8-hour average occupancy was 30 (26-32) patients for the 40 licensed treatment bays. For Q2, this was 40 (37-41) patients; for Q3, this was 47 (45-50) patients; and for Q4, this was 58 (55-63) patients. Hence, ED crowding, as defined by Q4, was really a systematic violation of the treatment capacity of the ED for this hospital. Only for Q1 was the ED treatment capacity within the limit set for our ED. Thus, this Q1 was the reference value we used for the study (Figure 1).

The overall mortality within 10 days was 0.94% (1018 of 108229 patients). Of those, 255 patients (0.24% of the total population) died in the ED and 763 patients (2.32% of the total population) died within 10 days in the hospital. Univariate analysis revealed that there was no significant association between ED crowding (Q4) and overall risk of mortality. (Figure 2, panel A). Similarly, univariate analysis revealed that death in ED was not significantly associated with ED crowding (Q4) (Figure 2, panel B). For follow-up patients, univariate analysis showed that there were significantly *fewer* deaths with ED crowding (Q4) than with Q1 (HR 0.72 [0.59-0.88]; $p=0.001$) (Figure 2, panel C).

Multivariate analyses without adding severity of illness risk factors revealed that the risk of mortality was significantly *lower* in Q4 than in Q1 for the entire study cohort of 108229 patients, as well as for the group of patients who died in the ED and for the follow-up patients (data not shown). However, when severity of illness risk factors (transport method and triage acuity) were added to the model, the significance of the associations between ED crowding (Q4) and death completely disappeared for all three patient groups (all P values were >0.2) (Figure 2, panels A, B, C)

However, the result for hospital stays was different. When controlling for *all* baseline risk factors (including severity of illness factors), ED crowding was independently associated with a longer duration of hospital stay (HR 0.89 [0.85-0.93]; $p<0.0001$; and HR 0.91 [0.88-0.95]; $p<0.0001$ for Q1 and Q2, respectively). The median duration of hospital stay was 24 hours longer in Q4 as compared to Q1 (172 hours versus 148 hours) For the association between ED occupancy and the duration of ED stay of follow-up patients, Q4 was associated with less risk of extended ED stay beyond 8 hours in multivariate analysis after controlling for all baseline risk factors (OR 0.6 [0.5-0.7]; $p<0.0001$). Finally, the risk of developing hospital-acquired pneumonia was significantly higher in Q4 than in Q2 (OR 1.31 [1.06-1.63]; $p=0.01$), but not significant for Q4 versus Q1 (OR 1.24 [0.96-1.62]; $p=0.09$). Q4 was not associated with any of the other studied adverse events occurring within 10 days of ED admission (Figure 3).

DISCUSSION

We conducted a large prospective observational cohort study in one tertiary referral center. After controlling for baseline risk factors, including two indicators of severity of illness upon ED admission, we found that ED crowding was not independently associated

with mortality within 10 days of ED admission. By contrast, when controlling for these factors, ED crowding was independently linked with a longer duration of hospital stay and tended to be associated with a higher incidence of hospital-acquired pneumonia, but not with any of the other studied adverse events occurring within 10 days of ED admission. These results suggest that when the ED experiences crowding it may lead to more morbidity, reduce the efficiency of patient care, and thereby extend the duration of hospitalization. It did not appear, however, to lead to higher mortality rates in the study population of this particular tertiary referral center.

Our finding that ED crowding was *not* an independent risk factor for in-hospital mortality within 10 days of ED admission was surprising, as this was what has been concluded in previous studies [14, 15, 19, 20]. Various factors could explain this apparent discrepancy, including differences in study design, sample sizes, and statistical methodology, such as the degree of controlling for confounding variables. In our study, which is the largest such one to date, the unexpected apparent association between ED crowding and lower mortality in the univariate analysis completely disappeared after statistically controlling for confounding factors. In particular, inclusion of the “severity of illness” variables in the multivariate model neutralized the appearance of an association. The results of a similar study by Miro et al. did show a significant positive correlation between weekly number of ED visits and mortality rates [19]. However, their analyses did not control for the possible confounding effects of baseline factors, such as severity of illness, an oversight that may have led to a spurious association.

Richardson also found higher in-patient mortality related to ED crowding 10 days after ED admission [15]. However, their study also had fewer subjects and thus may have lacked the statistical power to adequately control for the confounding effects of baseline risk factors. Moreover in that study, patients seen during crowded shifts were triaged as having

slightly higher acuity and received care at a much lower performance level according to standard measures. In our study, the opposite occurred, with apparently more severely ill patients being admitted during the less crowded periods. Hence, after accounting for the effects of severity of illness, the apparent association between undercrowding and death disappeared.

Sprivulis et al. found a linear relationship between crowding and death on day 7 and day 30, one that controlled for the effects of age, diagnosis, triage acuity, and mode of transport [14]. However, the authors used a questionable proxy measure of crowding that was a combination of hospital occupancy and ED access block, which makes comparison with the current study difficult. In our study, the analysis focused specifically on ED crowding and was corrected for hospital occupancy.

Four out of the 5 studied morbidity outcome measures were not associated with ED crowding within 10 days of ED admission, with or without controlling for the possible effects of baseline risk factors. Hospital-acquired pneumonia was the only adverse event that appeared to be independently related to ED crowding, although the comparison with the lowest ED occupancy quartile showed only a trend, and the statistical significance applied only to the comparison with the second quartile of ED occupancy. Possible explanations for this association are suboptimal physiotherapy, insufficient aspiration of sputa, and/or insufficient mobilization of the patient during ED crowding.

Finally, the duration of hospital stay was significantly longer when patients were admitted during ED crowding, again with and without controlling for risk factors. Interestingly, a shorter ED stay was linked with ED crowding. The most plausible explanation for this observation is that patients were being rushed to hospital wards exactly because of the

ED crowding. During uncrowded periods, more extensive diagnostic tests likely are ordered in the ED.

It is reasonable to assume that ED crowding is not an isolated phenomenon, but more likely a manifestation of general hospital crowding. If patients are indeed being moved to hospital wards more quickly due to ED crowding, we can assume that more patients will be admitted to alternative hospital beds, instead of waiting for empty beds on appropriate hospital wards. Nevertheless, whatever the explanation is for longer hospital stays being associated with ED crowding, its occurrence will inevitably increase hospital costs. Indeed, although the current study did not examine financial data, previous studies have reported significant increases in total hospital costs during ED crowding due to longer hospital stays [16, 21, 29].

LIMITATIONS

The findings of this study are subject to several limitations. First, the study was performed in only one [xxx] tertiary referral university hospital. As a result, caution should be used in generalizing our findings to other hospitals or countries. Given the health and financial implications, it would be valuable to repeat such a study in a multi-center setting. Gathering information on severity of illness was especially valuable. It would be preferable to further control for severity of illness in more detail; for example, by using the Charlson Comorbidity Index [30]. However, currently this index is not being widely used in clinical practice. Second, during night shifts in the hospital studied here, triage may have been incomplete,

which could lead to a bias in controlling for severity of illness, as sicker patients may be more likely to visit the ED during the night. However, removing triage acuity from the model did not affect our conclusions. Third, the ED occupancy rate was used as a measure for crowding. It is a relatively crude measure, not taking into account adequately non urgent cases that can wait and therefore do not really create crowding. Fourth, although the study was large, it may still have been too underpowered to detect small differences between the ED crowding quartiles for the hospitalized patients only. Fifth, we only analyzed the relationship between ED crowding and five morbidities, duration of hospital stay, and mortality. We cannot exclude the possibility that other morbidities could become more prevalent in cases of ED crowding. Furthermore, there was no follow-up of outpatients and left-without-being-seen patients, who might suffer the most from ED crowding due to “mistriage”, non-treatment, and errors including inappropriate discharge. Finally, demographic characteristics and risk factors were extracted from a hospital information system, whereas data required to score the adverse morbidity events were extracted from electronic medical records. The quality of retrieved data is obviously dependent on the quality of stored data. However, we are confident that we addressed this concern, since we cross-checked information stored in the hospital information system with that located in the electronic medical records system. Furthermore, scoring of adverse events was not based on disease codes, or on reported primary or secondary diagnoses. Instead, various sources were used to detect adverse events, such as reports on radiography, biochemistry, and cultures. The likelihood that those different sources would be missing simultaneously is small compared to the underreporting of morbidities.

Conclusion

328 In conclusion, after extensively controlling for risk factors, we determined that ED crowding
329 in this study was not independently associated with in-hospital mortality within 10 days of ED
330 admission, but *was* independently related to some types of morbidity and a longer duration of
331 hospital stay.

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Article summary

1. Why is this topic important?

ED crowding is an ongoing major, international problem that affects patients and providers. Clinical and organizational implications of ED crowding should remain subject of investigation.

2. What does this study attempt to show?

To investigate whether the highest quartile of ED occupancy is associated with death, several morbidity outcomes and a longer duration of hospital stay after controlling for baseline risk factors.

3. What are the key findings?

After controlling for risk factors we showed that ED crowding was associated with longer hospital stays but not with increased mortality. These findings suggest that ED crowding has a negative impact on efficiency and cost of patient care.

4. How is patient care impacted?

In order to achieve better quality assessment, introduction of compulsory centralization of data with indicators of severity of illness appears to be mandatory.

6. Table 1. Baseline Characteristics of All Patients (N=108229) Stratified by Quartile

Characteristic	Q1	Q2	Q3	Q4	P-values
Number	27057	27081	27034	27057	
Age (y) - Median (QR)	41 (22-62)	44 (22-65)	45 (23-66)	45 (22-68)	<0.0001
Male gender - N (%)	14555 (53.8)	14211 (52.5)	13907 (51.4)	13767 (50.9)	<0.0001
Clock time of admission (h:min) - Mean (SD)	10:12 (6:36)	13:42 (5:30)	15:12 (4:12)	16:00 (2:48)	<0.0001
Medical assisted transport - N (%)	1163 (4.3)	945 (3.5)	914 (3.4)	785 (2.9)	<0.0001
Weekend admission - N (%)	12752 (47.1)	10886 (40.2)	5584 (20.7)	670 (2.5)	<0.0001
Winter admission - N (%)	5431 (20.1)	5909 (21.8)	6891 (25.5)	7968 (29.5)	<0.0001
Hospital occupancy % - Median (QR)	78.2 (74.6-81.9)	79.5 (75.8-82.8)	81.1 (77.7-83.9)	82.3 (79.8-84.5)	<0.0001
Triage code* - N (%)					<0.0001
ESI 1	147 (0.9)	177 (0.8)	196 (0.8)	203 (0.8)	
ESI 2	3240 (18.8)	5143 (22.3)	5908 (23.7)	6096 (23.3)	
ESI 3	5910 (34.4)	8890 (38.6)	9822 (39.4)	10252 (39.1)	
ESI 4	6469 (37.6)	7396 (32.1)	7612 (30.5)	8125 (31.0)	
ESI 5	1430 (8.3)	1427 (6.2)	1420 (5.7)	1519 (5.8)	

7. N=Number; Q1-4: first, second, third, fourth quartile; SD=standard deviation; QR=interquartile range; ESI=Emergency Severity Index (levels 1-5).
8. *Triage performed on 91382 patients (84.4%).

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433 **Table 2. Baseline Characteristics of ED-only Patients (Non-follow-up Patients)**
 434 **(N=75363) per Quartile**

Characteristic	Q1	Q2	Q3	Q4	p-values
Number	19955	18989	18321	18098	
Age (y) – Median (QR)	32 (18-52)	33 (16-53)	32 (15-53)	31 (14-53)	0.0006
Male gender - N (%)	10739 (53.8)	10006 (52.7)	9457 (51.6)	9161 (50.6)	<0.0001
Clock time of admission (h:min) - Mean (SD)	10:12 (6:30)	13:48 (5:30)	15:24 (4:12)	16:12 (2:48)	<0.0001
Medical assisted transport - N (%)	474 (2.4)	367 (1.9)	375 (2.1)	340 (1.9)	0.0002
Weekend admission - N (%)	9590 (48.1)	7972 (41.9)	4205 (22.9)	537 (2.9)	<0.0001
Winter admission - N (%)	4000 (20.1)	4223 (22.2)	4725 (25.8)	5314 (29.4)	<0.0001
Hospital occupancy % - Median (QR)	78.8 (75.6-83.2)	80.1 (76.4-84.4)	82.4 (78.5-85.6)	83.6 (80.9-86.3)	<0.0001
Triage code* - N (%)					<0.0001
ESI 1	47 (0.4)	57 (0.4)	70 (0.4)	65 (0.4)	
ESI 2	1562 (12.1)	2415 (15.1)	2719 (16.3)	2784 (16.0)	
ESI 3	3784 (29.4)	5342 (33.4)	5681 (34.0)	5720 (32.9)	
ESI 4	6157 (47.8)	6892 (43.1)	7064 (42.2)	7522 (43.2)	
ESI 5	1332 (10.3)	1287 (8.1)	1200 (7.2)	1308 (7.5)	

435 N=Number; Q1-4: first, second, third, fourth quartile; SD=standard deviation; QR=interquartile range; ESI=Emergency Severity Index
 436 (levels 1-5).

437 *Triage performed on 63008 patients (83.6%).

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Table 3. Baseline Characteristics of Follow-up Patients (N=32866) per Quartile

Characteristic	Q1	Q2	Q3	Q4	P-values
Number	7102	8092	8713	8959	
Age (y) - Median (QR)	64 (47-78)	65 (50-78)	66 (51-79)	68 (52-79)	<0.0001
Male gender - N (%)	3816 (53.7)	4205 (51.9)	4450 (51.1)	4606 (51.4)	0.005
Clock time of admission (h:min) - Mean (SD)	10:12 (6:48)	13:24 (5:18)	14:36 (3:54)	15:24 (2:36)	<0.0001
Medical assisted transport - N (%)	689 (9.7)	578 (7.1)	539 (6.2)	445 (4.9)	<0.0001
Weekend admission - N (%)	3162 (44.5)	2914 (36.0)	1379 (15.8)	133 (1.5)	<0.0001
Winter admission - N (%)	1431 (20.2)	1686 (20.8)	2166 (24.9)	2654 (29.6)	<0.0001
Hospital occupancy % - Median (QR)	80.7 (78.4-82.7)	81.3 (79.1-83.2)	81.9 (79.8-83.7)	82.8 (80.9-84.5)	<0.0001
Triage code* - N (%)					0.0008
ESI 1	100 (2.3)	120 (1.7)	126 (1.5)	138 (1.6)	
ESI 2	1678 (38.9)	2728 (38.8)	3189 (38.8)	3312 (37.7)	
ESI 3	2126 (49.3)	3548 (50.4)	4141 (50.4)	4532 (51.5)	
ESI 4	312 (7.2)	504 (7.2)	548 (6.7)	603 (6.9)	
ESI 5	98 (2.3)	140 (2.0)	220 (2.7)	211 (2.4)	

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N=Number; Q1-4: first, second, third, fourth quartile; SD=standard deviation; QR=interquartile range; ESI=Emergency Severity Index (levels 1-5).

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*Triage on 28374 patients (86.3%).

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Figure 1. Quartiles of ED occupancy.

(A) Frequency density plot of individual mean ED occupancy rates for the total cohort of patients for 40 licensed treatment bays. (B) All individual mean occupancy rates for the total cohort of patients divided into quartiles. Q4 was operationally defined as “ED crowding.”

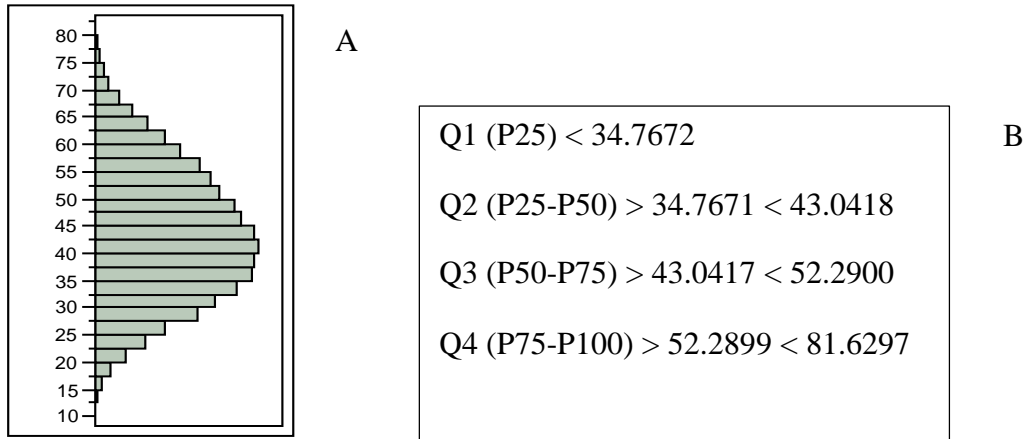
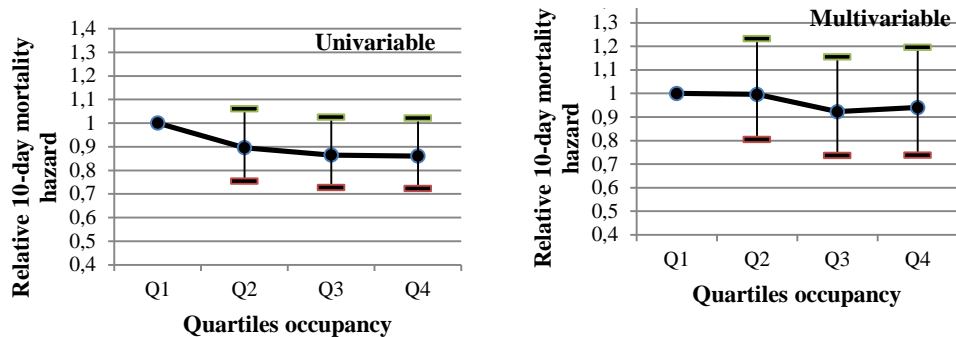


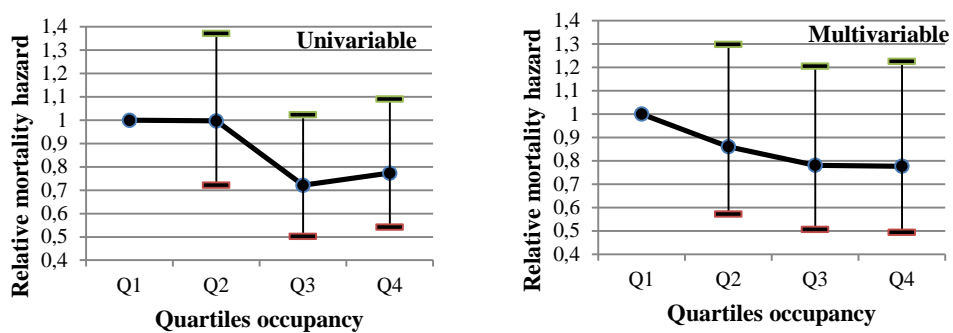
Figure 2. Relative risk of mortality.

(A) Univariate (left graph) and multivariate (right graph) risk of mortality within 10 days for the total cohort of patients per quartile occupancy. In both univariate and multivariate analysis, no significant association was found between ED crowding (Q4) and overall risk of mortality. (B) Univariate (left) and multivariate (right) risk of mortality for patients who died in the ED per quartile occupancy. In both univariate and multivariate analysis, no significant association was found between ED crowding (Q4) and death in ED. (C) Univariate (left) and multivariable (right) risk of mortality within 10 days for follow-up patients admitted to hospital. In the univariate analysis, there were significantly fewer deaths with ED crowding compared to Q1 (**p=0.001; Q4 versus Q1). Significance disappeared when controlling for all baseline factors, including severity of illness.

A. Relationship between ED occupancy per quartile and 10-day mortality hazard for total cohort of patients



B. Relationship between ED occupancy per quartile and mortality for deaths in ED



C. Relationship between ED occupancy per quartile and 10-day mortality hazard for follow-up patients

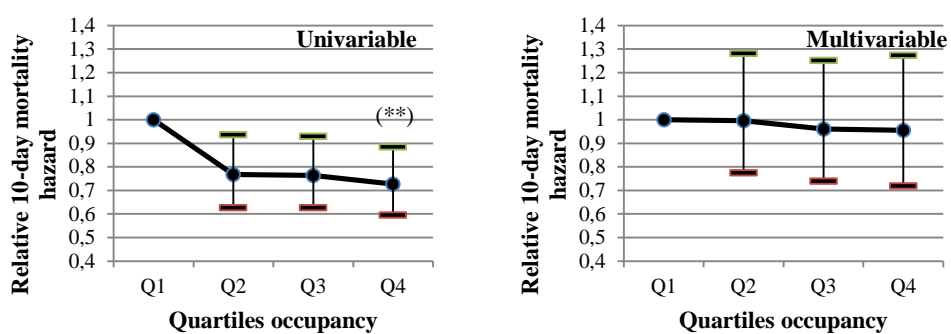
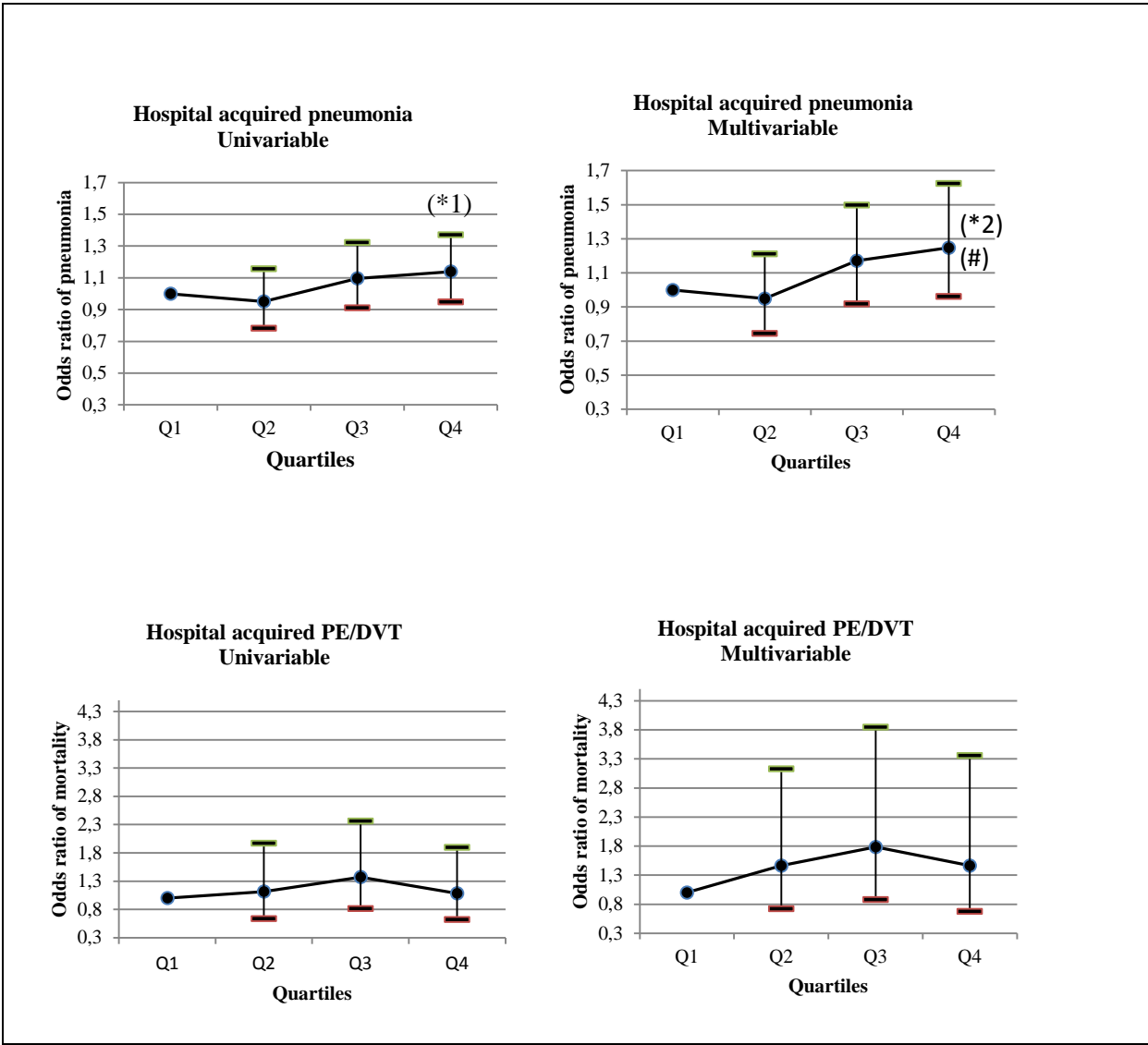
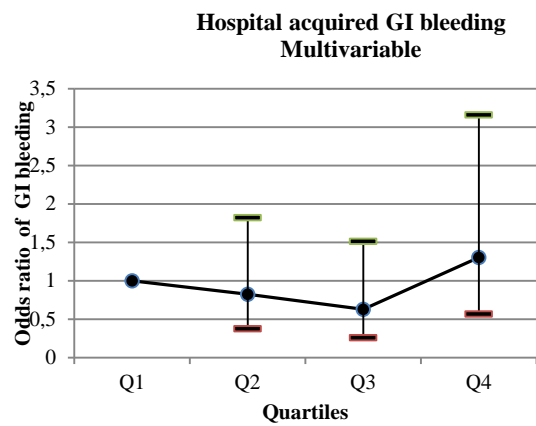
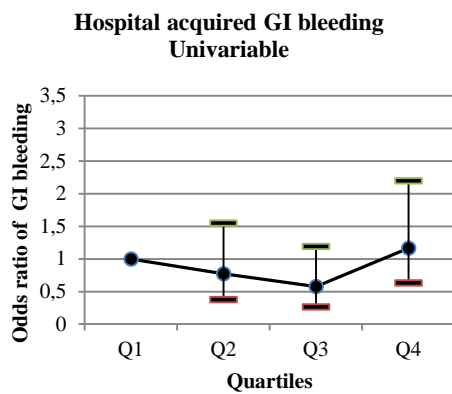
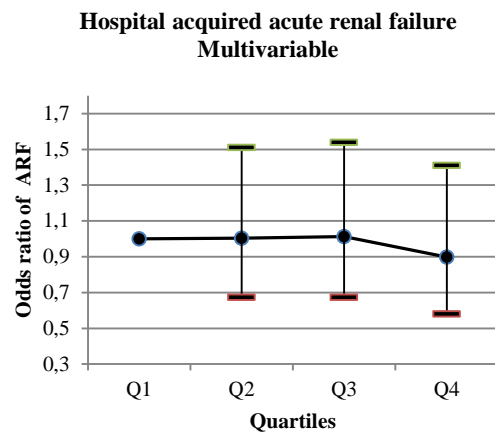
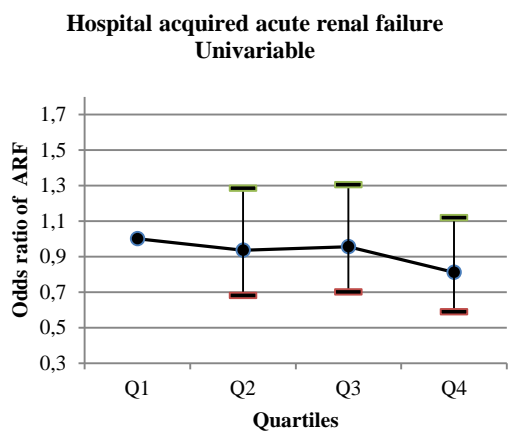
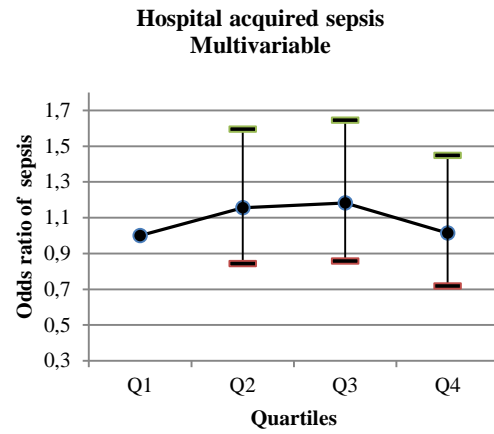
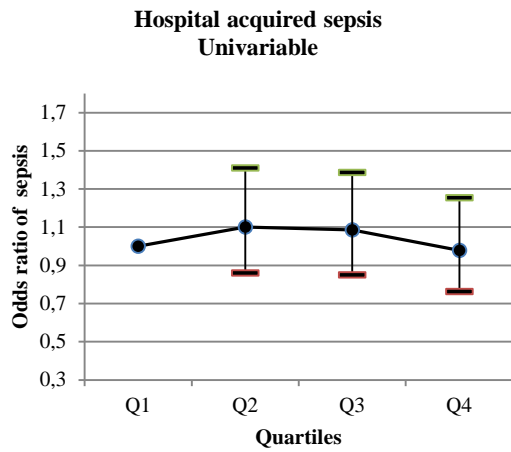


Figure 3. Univariate and multivariate odds ratios for morbidities in relation to ED crowding

In univariate analyses, hospital-acquired pneumonia developed significantly more frequently when patients were admitted during ED crowding (Q4) when compared to Q2 [(*) $p=0.04$ Q4 versus Q2]. In multivariate analyses, controlling for all baseline factors, including severity of illness, the risk of developing hospital-acquired pneumonia was significantly higher in Q4 than in Q2 [(*) $p=0.01$ Q4 versus Q2], but not significant for Q4 versus Q1 [(#) $p=0.09$].





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